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TITLE: Exposure apparatus and method

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Abstract Text - ABTX (1):
    A projection exposure method for exposing a substrate through a projection
optical system with a predetermined pattern formed on a mask. The method
includes the steps of calculating an amount of lateral variation of a pattern
image in a direction perpendicular to an optical axis of the projection optical
system, determining a distortion produced solely by the projection optical
system, obtaining a total expected distortion by a summation of the distortion
produced solely by the projection optical system and the calculated variation
of the positions at which the image of the pattern of the mask is formed, and
exposing the substrate while partially **correcting** the positions at which the
image of the pattern of the mask is formed through the projection optical
system based on the total expected distortion.

Brief Summary Text - BSTX (3):
    In a photolithographic process for fabricating semiconductor devices or
other products, there have been used various projection exposure apparatus
including stepping projection exposure apparatus called stepping projection
aligners or steppers, as well as scanning projection exposure apparatus called
scanning projection aligners or step-and-scan projection aligners. These
projection exposure apparatus use a projection optical system

(or projection
lens) which has to provide an extremely high resolution
approaching the
theoretical resolution limit. In order to support such a
high resolution, many
projection optical systems have certain mechanisms for
measuring various
factors in the resolution (such as, the atmospheric pressure
and the ambient
temperature) and then **correcting** the image formation
characteristics of the
projection optical system depending on the result of such
measurement. For
higher resolution, projection optical systems are designed to
have a large
numerical aperture. As a result, the depth of focus is very
small. Thus, many
projection optical systems have a autofocus mechanism which
may comprise an
oblique-incidence focus position detection system (or AF
sensor). The AF
sensor serves to measure the focus position (or the position
in the direction
along the optical axis of the projection optical system) of
the surface of a
wafer (or substrate) which typically has some irregularities.
 The autofocus
mechanism brings the surface of the wafer into a position at
which it will be
coincident with the image plane of the projection optical
system, based on the
result of such measurement.

Brief Summary Text - BSTX (4):
    In recent years, image formation errors caused by
deformation of a mask or
reticle have become a problem. If substantially all the
pattern-bearing
surface area of a reticle is deformed down toward the
projection optical
system, the average position of the image plane (or image
surface) of the
pattern-bearing surface is displaced downward, so that the
focus position of a
wafer could suffer from defocusing if it were not adjusted.
Further, when the
pattern-bearing surface of a reticle is deformed, the

positions of the pattern,
which are perpendicular to the optical axis of the projection
optical system,
on the pattern-bearing surface may also is displaced. Such
lateral
displacements (or displacements in the direction
perpendicular to the optical
axis of the projection optical system) may cause distortion
errors.

Brief Summary Text - BSTX (6):
    There have been many proposals to reduce lens aberrations
contributed to by
factors involved in the fabrication process. One such
technique uses one or
more aberration **correction** plates disposed between the
projection optical
system and the wafer (or glass substrate), for canceling out
the aberrations.
Specifically, any residual aberrations which remain after
final adjustment of a
lens are canceled out by the reverse aberrations
intentionally produced by the
aberration **correction** plates so as to minimize the resultant
lens aberrations.
The residual aberrations may be determined by making and
analyzing a test.
print using that lens together with a test reticle having
evaluation patterns
formed thereon, or by measuring the position of aerial images
of evaluation
patterns of a test reticle formed by that lens by means of a
measuring
photodetector.

Brief Summary Text - BSTX (7):
    There have been further factors affecting the final image
formation
characteristics of a lens, which relate to the accuracy (or
drawing errors) in
the evaluation patterns of a test reticle. In particular,
the patterning
accuracy (including the linewidth accuracy) of a test reticle
is of great
concern. In order to **correct** errors arising from
insufficient patterning

accuracy, a system has been used in which the pattern positions (or the
distances between the patterns) of a finished test reticle are measured and
stored using a precision coordinate measurement device, and the positions of
the projected images are **corrected** by an utilization of the stored pattern
positions.

Brief Summary Text - BSTX (8):
　　As described above, when the image formation characteristics of a projection
optical system are evaluated, measurement errors due to insufficient patterning
accuracy of an evaluation reticle may be **corrected** by an utilization of the
pattern positions which are measured and stored in advance. However, there are
further structural factors affecting the final or total image formation
characteristics of the projection exposure apparatus, including the flatness of
the exposure area of an evaluation reticle, flatness of the area outside the
exposure area of a reticle, and the deflection of a reticle when it is loaded
on the projection exposure apparatus. In the past when requirements for the
image formation characteristics were less severe, the need for various
accuracies relating to these structural factors did not arise. However, in
recent years, requirements for the patterning accuracy of semiconductor chips
and the registration accuracy between **layers** of the semiconductor chips have
become very severe, so that the accuracies relating to the above structural
factors have become of more significance in order to meet such requirements.

Brief Summary Text - BSTX (11):
　　However, holding a mask on a mask holder in this manner suffers from a
problem that the mask 900 is deflected by the gravity as

shown in FIG. 30(A).
This results in the lateral displacements of the features of the pattern formed
on the mask 900 as well as the curve of the image surface defined by the
projection optical system. Further, irradiation of the exposure light rays
onto the mask 900 during exposure operations imparts irradiation heat to the
mask 900 and increases its temperature, this results in the thermal expansion
of the mask 900. Since the mask 900 is secured at its peripheral area onto the
mask holder 902, the mask 900 is deformed as shown in FIG. 30(B). As the
result, the pattern on the mask 900 is also deformed, which may
disadvantageously produce variation In the distortion of the projected pattern
image and/or add to the curvature of the image surface so that the depth of
focus in the pattern-bearing surface of the mask become inconveniently smaller.
With today's highly miniaturized patterns, even a minute **deformation** of the
pattern can be of great concern.

Brief Summary Text - BSTX (12):
   Apart from deflection caused by gravity, the **deformation** of a mask or
reticle may be also caused In the polishing process of the glass plate forming
the reticle, or may be caused depending on insufficient flatness of one or both
of the contact surfaces of the reticle and the reticle holder, which are forced
to come into contact with each other by vacuum suction. Since there is
difference in the deflections between reticles, or between projection exposure
apparatus, a deflection of a particular reticle has to be measured when it is
held on the reticle holder of a particular projection exposure apparatus in
order to obtain an accurate reticle **deformation**.

Brief Summary Text - BSTX (13):
    One method for measuring the **deformation** of the
pattern-bearing surface of a
reticle held on the reticle holder of a projection exposure
apparatus by vacuum
suction may comprise the steps of making and analyzing a test
print using the
projection optical system of that projection exposure
apparatus. The selected
features of the pattern formed on the pattern-bearing surface
of the reticle
are projected through the projection optical system onto a
wafer for
evaluation. This projection exposure is repeated while the
focus position of
the wafer is varied in a stepwise manner. After the
development process of the
resist **layer** on the wafer, the resist patterns thus formed
are examined for
their contrast, and the exposure specifications for the
resist patterns of the
highest contrast among those corresponding to the same
features of the reticle
pattern indicate the best-focus positions of the projected
images of the
respective features of the reticle pattern. Then, from the
displacements of
the best-focus positions, the **deformation** of the
pattern-bearing surface of the
reticle may be calculated quantitatively to a certain extent.

Brief Summary Text - BSTX (16):
    In particular, for a scanning projection exposure
apparatus, since the
reticle stage used therein has to show sufficient rigidity to
prevent any
harmful **deformation** when accelerated/decelerated for movement
in synchronism
with the wafer stage for scanning, the reticle stage is
generally given a
sufficient thickness, thereby usually the bottom surface of
the reticle is
close to the upper end of the projection optical system.
Further, the smaller
the space distance between the reticle and the projection
optical system, the
easier the projection optical system may be designed, so that

projection
optical systems having a greater precision tend to provide less space between
the reticle and the projection optical system. Thus, it is difficult to
dispose a position sensor for measuring the surface shape of a reticle in the
space between the projection optical system and the reticle.

Brief Summary Text - BSTX (17):
    Moreover, a position sensor for measuring the surface shape of a reticle
must have a high stability against aging. This is because even such a
variation in measurements provided from the position sensor, that is actually
caused by aging, is interpreted as indicating a variation in the surface shape
of the reticle, leading to an erroneous **correction** of the image formation
characteristics.

Brief Summary Text - BSTX (21):
    In the case where the reticle support portions 943 for supporting the
reticle R thereon are formed as vacuum chucks, the deflection of the reticle R
by the gravity may be suppressed by the **corrective** forces acting from the top
surfaces of the reticle support portions 943, when the top surfaces are level
or extend horizontally. However, since the recent years' projection lenses
have a very high numerical aperture with a extremely small depth of focus, and
there is the need for the improvement of the overlay accuracy in order to
support the more and more reducing linewidth, even a relatively low level of
residual deformations of reticles after the **correction by the**
corrective forces
by vacuum chucks may arise a problem.

Brief Summary Text - BSTX (22):
    As regards the reticles used for exposure of silicon

wafers, 5-in. square
reticles are being replaced by 6-in. square reticles.
Simultaneously, reticles
of 0.09-in. in thickness are being replaced by those of
0.25-in. in thickness
for the purpose of reducing any errors which may occur due to
the **deformation**
of reticles. In view of recent trends in the semiconductor
device industry,
greater exposure fields and greater reticle sizes are
expected to be required
and become common in the near future. The expected next
generation of reticles
are 9-in. square reticles, for which the thickness of about
0.5 in. would be
required in order to meet both a focus condition of .+-.0.1
mm and a distortion
tolerance or 0.005 mm. It is expected that 9-in. square
reticles would become
common in 2000 A.D., where scanning projection exposure
machines in which a
reticle and a wafer are moved in synchronism with each other
would be the
prevailing exposure machines. A reticle of a greater
thickness means a heavier
reticle, which may arise a problem regarding the secure
holding of a reticle by
the reticle holder since a reticle must be accelerated and
decelerated for
scanning projection exposure. Further, for enhancing the
throughput, high
speed operations of exposure machines are required, which
would lead to a
limitation on the weight of a reticle. Thus, the thickness
of a reticle should
be a compromise between the anti-deflection and throughput
requirements, which
may not be ideal in view of the anti-deflection capability.
Accordingly, it is
difficult to meet both the desired focus condition and
distortion tolerance
with any of conventional techniques.

Brief Summary Text - BSTX (27):
   The fourth object of the present invention is to provide
projection exposure
apparatus and method with which the thickness and weight of a

reticle may be
suppressed and any pattern transfer errors due to the
deformation of the
reticle may be eliminated.

Brief Summary Text - BSTX (28):
    In order to achieve the above-mentioned first object, in
accordance with the
present invention, there is provided a projection exposure
apparatus for
projecting an image of a pattern formed on a mask onto an
object of exposure,
comprising: a deflection detection device for detecting
deflection of the mask;
a deflection **correction** device for **correcting** deflection of
the mask; an
arithmetic device for calculating a deflection **correction**
value for the
deflection **correction** device based on the detection result
obtained by the
deflection detection device; and a control device for
controlling the
deflection **correction** device in accordance with the
deflection **correction** value
calculated by the arithmetic device.

Brief Summary Text - BSTX (29):
    In several embodiments of significance, the deflection
detection device
comprises: a light-beam-projecting device for obliquely
projecting a light beam
onto the mask; and a light-beam-detecting device for
detecting a reflected
light beam projected by the light-beam-projecting device and
reflected by the
mask so as to produce a detection signal corresponding to the
variation in the
position at which the reflected light beam is received.
Further, the
deflection **correction** device may **correct** deflection of the
mask by changing
pneumatic pressure, or alternatively, the deflection
correction device may
correct deflection of the mask by operating a piezoelectric
actuator element.

Brief Summary Text - BSTX (30):
    In accordance with this aspect of the present invention,
any deflection of
the mask produced by the gravity and/or the thermal expansion
is detected by,
for example, an oblique-incidence detection system. Based on
the detection
result, a deflection **correction** value is calculated and the
deflection is
corrected. As the result, any curvature of the pattern image
is suppressed and
an accurate and stable image of the mask pattern may be
obtained. In several
embodiments of significance, the deflection of the mask is
corrected and any
variation in the projected image is **corrected** by changing
pneumatic pressure or
operating a piezoelectric actuator element.

Brief Summary Text - BSTX (31):
    In order to achieve the above-mentioned second object, in
accordance with
the present invention, there is provided a projection
exposure method for
making a projection exposure of an image of a pattern formed
on a mask through
a projection optical system onto a substrate, comprising the
steps of:
measuring and. storing a surface shape of a pattern-bearing
surface of the
mask; and making an exposure while partially **correcting,**
based on the surface
shape as stored, the position at which an image of the
pattern of the mask is
formed through the projection optical system.

Brief Summary Text - BSTX (32):
    With this projection exposure method, for example, a
correction mechanism
may be used for **correcting** image formation characteristics
including the
distortion by driving one or some of the lens elements of the
projection

optical system. Further, for example, by using a distortion evaluation mask
having evaluation patterns formed thereon, the positions of projected images of
the evaluation patterns are measured so as to determine the distortion actually
produced by the projection optical system. However, the determined distortion
contains error components due to lateral displacements of features of the
pattern on the pattern-bearing surface produced by the **deformation** of the
surface shape thereof. Therefore, from the measured surface shape of the
pattern-bearing surface of the distortion evaluation mask, a distribution of
expected displacements of projected images of the evaluation patterns from
their desired projection positions is calculated. Then, the measurements of
the distortion is adjusted with the expected displacements so as to derive a
distortion to be produced solely by the projection optical system. In the
actual exposure process, the surface shape of the mask for the actual exposure
process is measured, and the measurement result is used to calculate the
expected lateral displacements of the points in the projected image which are
expected to be produced by the surface shape. Then, the expected displacement
of the projected image is added to the distortion which is produced solely by
the projection optical system so as to derive a total expected distortion. The
correction mechanism **corrects** the total expected distortion, so that excellent
image formation characteristics may be obtained even when the mask has
irregularities in its surface or suffers from tilt.

Brief Summary Text - BSTX (33):
    This projection exposure method may be also applied to projection exposure
apparatus of the type called step-and-scan projection aligners, in which the

surface shape of a mask may possibly vary depending on the position on the mask
in the scanning direction, so that the distortion **correction** value has to be
varied while the mask is moved for scanning. In such a case, the **correction**
mechanism may control the distortion **correction** value depending on the position
of the mask during an scanning projection exposure operation, so that excellent
image formation characteristics may be obtained over the entire region in the
scanning direction. Further, in such a case, if the distortion of the
projection optical system has been well **corrected,** the distortion **correction**
may be performed such that only the lateral displacements of the points in the
projected image which are produced by the surface shape of the pattern-bearing
surface of the mask may be canceled out.

Brief Summary Text - BSTX (34):
    In order to achieve the above-mentioned second object, in accordance with
the present invention, there is also provided another projection exposure
method for making a projection exposure of an image of a pattern formed on a
mask through a projection optical system onto a substrate, the mask being
supported by a predetermined support member, comprising the steps of: measuring
and storing any irregularities (including tilt) in a contact surface of the
mask in contact with the support member; and making an exposure while partially
correcting, based on the irregularities in the contact **surface as stored,** the
position at which an image of the pattern of the mask is formed through the
projection optical system.

Brief Summary Text - BSTX (35):
    With this projection exposure method, the mask may be

secured onto the
support member by vacuum suction. In such a case, if the contact surfaces
(245A to 245D) of the mask which are in contact with the support member are
tilted as shown in FIG. 17(B), the mask is caused to curve as shown in FIG.
17(C) when it is secured by the vacuum suction, so that the flatness of the
mask is deteriorated. This problem may be solved by: determining, based on any
irregularities in the contact surfaces between the mask and the support member,
an expected variation in the irregularities in the contact surface of the mask
which is expected to be produced when the mask is secured onto the support
member by vacuum suction; adjusting the measurement result of the distortion of
the projection optical system by the expected lateral displacement of the
projected image; and **correcting** the image formation characteristics based on
the adjusted distortion, so that excellent image formation characteristics may
be obtained.

Brief Summary Text - BSTX (36):
   In order to achieve the above-mentioned second object, in accordance with
the present invention, there is also provided further another projection
exposure method for making a projection exposure of an image of a pattern
formed on a mask through a projection optical system onto a substrate, the mask
being supported by a predetermined support member, comprising the steps of:
measuring and storing any irregularities (including tilt) in a contact surface
of the support member in contact with the mask; and making an exposure while
partially **correcting,** based on the irregularities in the contact surface as
stored, the position at which an image of the pattern of the mask is formed
through the projection optical system. With this projection

exposure method,
if the contact surfaces of the support member in contact with the mask are
tilted, the mask is caused to curve as shown in FIG. 17(A) when it is secured
by the vacuum suction onto the contact surfaces. This problem may be solved
by: determining an expected variation in the irregularities in the surface of
the mask which is expected to be produced when the mask is secured onto the
support member by vacuum suction; and **correcting** the measurements of the
distortion of the projection optical system based on the expected variation
thus determined, so that excellent image formation characteristics may be
obtained.

Brief Summary Text - BSTX (37):
    In order to achieve the above-mentioned second object, in accordance with
the present invention, there is also provided a projection exposure apparatus
for making a projection exposure of an image of a pattern formed on a mask
through a projection optical system onto a substrate, comprising: a measurement
system for measuring a surface shape of a pattern-bearing surface of the mask:
a storage for storing data representing the surface shape measured by the
measurement system; an image formation characteristics **correction** system for
partially **correcting** the position at which an image of the pattern of the mask
is formed through the projection optical system: and a control system for
making an exposure while **correcting,** through the image formation
characteristics **correction** system and based on the data in the storage
representing the surface shape, the position at which an image of the pattern
of the mask is formed through the projection optical system. With this
projection exposure apparatus, the projection exposure

methods described above
for achieving the above-mentioned second object may be
conveniently performed.

Brief Summary Text - BSTX (38):
    In order to achieve the above-mentioned third object, in
accordance with the
present invention, there is provided a scanning projection
exposure method in
which a mask and a substrate are moved in synchronism with
each other for
transferring a pattern formed on the mask through a
projection optical system
onto the substrate, comprising the steps of: measuring a
surface shape of a
pattern-bearing surface of the mask, prior to making a
scanning projection
exposure of the substrate with the pattern of the mask; and
correcting at least
one of 1) image formation characteristics of the projection
optical system and
2) the position of the substrate, based on the measurement
result of the
pattern-bearing surface, while making a scanning projection
exposure.

Brief Summary Text - BSTX (39):
    With this scanning projection exposure method, the surface
shape of the
pattern-bearing surface of the mask can be measured while at
least a part of
the pattern-bearing surface is in an area outside a transfer
area to be
transferred by the projection optical system, so that the
sensor for measuring
the surface shape of the mask may be disposed at a position
away from the
projection optical system to the scanning direction.
Accordingly, the sensor
may be disposed with ease even when there is little space
between the
projection optical system and the mask stage and be used to
measure the
deformation (or the deflection) of the mask. Either the
image formation
characteristics of the projection optical system or the

position of the
substrate may be **corrected** based on the measured **deformation,**
so that excellent
image formation characteristics may be obtained.

Brief Summary Text - BSTX (40):
   With this method, it is preferable to perform the
measurement of a surface
shape of the pattern-bearing surface of the mask while the
mask stands still at
a starting point for scanning or while the mask is being
accelerated for
scanning. That is, when a mask replacement is done, by
measuring a surface
shape of the pattern-bearing surface of the new mask once
while the
pattern-bearing surface of the new mask is at a starting
point for scanning or
in an acceleration region, the necessary **correction** may be
made during the
subsequent exposure operation. Further, in the case where
the surface shape
measurement is performed in the acceleration region, it is
unnecessary to
extend the stroke of the movement of the mask for the surface
shape
measurement. Moreover, the measurement of a surface shape of
the mask may be
alternatively performed while the mask is being scanned for
exposure, while the
mask is being decelerated after scanning, or while the mask
stands still after
deceleration.

Brief Summary Text - BSTX (41):
   In order to achieve the above-mentioned third object, in
accordance with the
present invention, there is also provided a scanning
projection exposure
apparatus in which a mask and a substrate are moved in
synchronism with each
other for transferring a pattern formed on the mask through a
projection
optical system onto the substrate, comprising: a shape
measurement system
defining a plurality of detection points in an area outside a

transfer area to
be transferred by the projection optical system, for
measuring a surface shape
of a pattern-bearing surface of the mask; and a **correction**
system for
correcting at least one of 1) image formation characteristics
of the projection
optical system and 2) the position of the substrate, based on
the measurement
result by the shape measurement system.

Brief Summary Text - BSTX (43):
    It is preferable to form a reference surface on a mask
stage for moving the
mask, such that the reference surface may be substantially
level with the
pattern-bearing surface of the mask. In such a case, at
first the measurement
by the shape measurement system is performed by measuring the
position of the
reference surface, and then measuring the surface position of
the reticle with
reference to the measured position of the reference surface.
That is, the
differential between the reference surface and the surface
position of the mask
is measured. By virtue of this, it is sufficient for the
shape measurement
system to have such stability for a very short time from when
the reference
surface has been measured to when the surface of the mask has
been measured.
Thus, even if the measurements produced from the shape
measurement system tend
to fluctuate within a certain period, the expected variation
in the image
formation characteristics may be determined with precision so
as to make an
appropriate **correction** for the variation.

Brief Summary Text - BSTX (45):
    In order to achieve the above-mentioned fourth object, in
accordance with
the present invention, there is provided a projection
exposure apparatus,
comprising: a first holder for holding a master matrix; an

illumination optical
system for illuminating the master matrix; a projection optical system for
focusing light rays which pass through the master matrix on a photosensitized
substrate so as to form an image thereon; and a second holder for holding the
photosensitized substrate; wherein error factors due to the **deformation** of the
master matrix produced by the gravity when the master matrix is held on the
first holder have been **corrected** through a design process of a projection lens.

Brief Summary Text - BSTX (46):
   In stead of, or in addition to, the **correction** of the errors through the
design process of the lens, an adjustment mechanism for the projection lens may
be used to **correct** the errors in an adjustment process for the apparatus.

Brief Summary Text - BSTX (47):
   In order to achieve the above-mentioned fourth object, in accordance with
the present invention, there is also provided a projection exposure method for
making a projection exposure of a pattern on a master matrix onto a
photosensitized substrate to transfer the pattern onto the substrate,
comprising the step of**: correcting,** through a design process of a projection
lens, error factors due to the **deformation** of the master matrix produced by the
gravity when the master matrix is held.

Brief Summary Text - BSTX (48):
   That is, any focus errors and distortion errors which are expected to be
produced by the deflection of a reticle are **corrected** through a reticle design
process or an adjustment process. Therefore, any pattern transfer errors due

to the **deformation** of a reticle may be eliminated even when the reticle has a
relatively small thickness.

Brief Summary Text - BSTX (49):
   With this projection exposure method, it is preferable to determine errors
due to the **deformation** of the master matrix produced by the gravity, through an
exposure process or a measurement process performed using a reference master
matrix, and adjust a projection lens of the projection optical system such that
the errors may be eliminated, and then make an actual exposure. In this case,
any errors are determined and **corrected** through the adjustment process, so that
even the error produced by the reticle chucks may be determined and **corrected**.

Drawing Description Text - DRTX (23):
   FIG. 21 is a schematic side elevation illustrating the **deformation** of the
image surface due to the **deformation** of the pattern-bearing surface of a
reticle;

Drawing Description Text - DRTX (26):
   FIG. 24 is a flow chart illustrating an exemplified sequence of operations
for performing exposure process while **correcting** the image formation
characteristics according to a further embodiment of the present invention for
achieving the above-mentioned third object;

Detailed Description Text - DETX (7):
   Referring again to FIG. 1, the output of the arithmetic operation unit 32 is
coupled to a pneumatic-pressure control unit 34, which is in communication with
a mask-deflection **correction** unit 38 through a conduit pipe 36. The

mask-deflection **correction** unit 38 comprises a box having
side walls with their
lower edges capable of airtight abutment with the mask 10 and
a top wall made
from a highly plane, highly clear glass plate not affecting
the exposure light
beam. Thus, the box together with the mask 10 defines an air
chamber 40. The
pneumatic pressure within the air chamber 40 may be
controlled by the
pneumatic-pressure control unit 34 in order to control any
deflection of the
mask 10. The pneumatic-pressure control unit 34 is capable
of controlling the
pneumatic pressure within the air chamber 40 depending on the
desired
pneumatic-pressure control value supplied from the arithmetic
operation unit
32.

Detailed Description Text - DETX (9):
    When the mask 10 is deformed, and thus changes its shape
from that shown by
solid lines to that shown by broken lines in FIG. 2(B) or
2(C), then the path
of the light beam from the light source 24 will be changed
from that shown by
solid lines to that shown by broken lines. The mask 10 is
deformed downward
and upward in FIGS. 2(B) and 2(C), respectively. The
detection signals from
the photodetector 30 produced when the position of the
incident point of the
light beam on the sensitive surface of the photodetector 30
varies are supplied
to the arithmetic operation unit 32. The arithmetic
operation unit 32 performs
comparison of the supplied detection signals with the
detection signals
representing the reference position as shown in FIG. 2(A),
and uses the
comparison to derive the magnitude of the deflection of the
mask 10 or the
displacement of a particular position on the mask 10 from the
reference
position mentioned above. The arithmetic operation unit 32
further calculates

the desired pneumatic-pressure control value which is required for **correcting**
the detected deflection of the mask 10.

Detailed Description Text - DETX (10):
    The desired pneumatic-pressure control value is supplied to the
pneumatic-pressure control unit 34, which controls the pneumatic pressure
within the air chamber 40 of the mask-deflection **correction** unit 38 so as to
correct the detected deflection of the mask 10. The **correction** of the
deflection of the mask 10 may be performed in this manner either continuously
or periodically at. an appropriate frequency so that any deflection of the mask
10 due to the gravity and/or possible thermal expansions may be **corrected**.

Detailed Description Text - DETX (11):
    As clearly understood from the above, according to the first embodiment, any
deflection of the mask 10 is detected by the mask-deflection detection system
22, the magnitude of the deflection as well as the desired pneumatic-pressure
control value for **correcting** the deflection are calculated by the arithmetic
operation unit 32, and the pneumatic pressure within the air chamber 40 of the
mask-deflection **correction** unit 38 is controlled by the pneumatic-pressure
control unit 34. In this manner, any lateral displacements of the images of
the features of a pattern and curvature of field both of which may result from
the deflection of the mask 10 due to the gravity, or any distortion and
curvature of field due to the thermal **deformation** of the mask 10, may be
reduced and thereby the projection of the mask pattern may be appropriately
performed.

Detailed Description Text - DETX (12):
   Referring next to FIG. 3, the second embodiment will be described in detail.
In FIG. 3, like elements are designated by like reference numerals as used for
the elements of the first embodiment. While the first embodiment utilizes an
air chamber for the purpose of **correcting** the deflection of the mask, the
second embodiment utilizes a set of piezoelectric actuator elements for the
same purpose. FIG. 3(A) shows a critical portion of the second embodiment, and
FIG. 3(B) shows the plan view of a mask. As shown in these figures, a set of
piezoelectric actuator elements 50A to 50H are disposed on the top surface of
the mask 10 along its peripheral edges. The piezoelectric actuator elements
50A to 50H are mounted onto a fixed frame 52 surrounding the mask 10 and
comprising four side members having an L-shaped cross-section. The mask is
held at a plurality of points on its under side along its peripheral edges onto
corresponding platens 54A to 54H by vacuum suction. The fixed frame 52 is
fixedly mounted onto the mask holder 54.

Detailed Description Text - DETX (14):
   The second embodiment comprises a mask-deflection detection system 22 having
the same arrangement as that used in the first embodiment described above. The
output of the photodetector 30 is coupled to an arithmetic operation unit 58,
the output of which is in turn coupled to a voltage control unit 58. The
output of the voltage control unit 58 is coupled to the set of piezoelectric
actuator elements 50A to 50H through the fixed frame 52. The arithmetic
operation unit 56 is capable of calculating the magnitude of the deflection of
the mask 10 based on the detection signals supplied from the photodetector 30

as well as calculating the desired voltage control value indicating the voltage
which has to be applied to the piezoelectric actuator elements 50A to 50H for
correcting the detected deflection of the mask 10. The voltage control unit 58
is capable of controlling the voltage to be applied to the piezoelectric
actuator elements 50A to 50H in accordance with the desired voltage control
values supplied thereto.

Detailed Description Text - DETX (16):
    FIG. 3(C) shows a cross-sectional side view of the mask 10 along line C3--C3
of FIG. 3(B). The mask 10 generally tends to deflect downward as indicated by
solid lines in FIG. 2(B). In the second embodiment, the platens 54C and 54H
are disposed inside to the piezoelectric actuator elements 50C and 50H as shown
in FIG. 3(C). Therefore, if the piezoelectric actuator elements 50C and 50H
are applied with a voltage having such polarity that cause them to elongate in
the vertical direction, the right and left ends (as viewed in FIG. 3(C)) of the
mask 10 is deflected downward as indicated by arrows FA. Since the platens 54C
and 54H serves as the fulcra, the central portion of the mask 10 is deflected
upward as indicated by arrow FB. By virtue of this, the downward deflection of
the mask 10 may be **corrected**. This control of the piezoelectric actuator
elements 50C and 50H is done by the voltage control unit 58. The other
piezoelectric actuator elements are controlled in the same manner.

Detailed Description Text - DETX (17):
    As clearly understood from the above, according to the second embodiment,
any deflection of the mask 10 is detected by the mask-deflection detection
system 22, the magnitude of the deflection as well as the

desired voltage
control values for **correcting** the deflection are calculated by the arithmetic
operation unit 56, and the voltages to be applied to the piezoelectric actuator
elements 50A-50H are controlled by the voltage control unit 58. In this
manner, this embodiment may achieve the same advantages as the first embodiment
described above.

Detailed Description Text - DETX (19):
    A projection optical system 106 is disposed on the beam-exiting side of the
mask 102. FIG. 5 shows an exploded perspective view of a critical portion of
the projection optical system 106. As seen, the projection optical system 106
comprises first and second lens element 108 and 110 between which three
piezoelectric actuator elements 112A-112C are disposed along their peripheral
edges. The piezoelectric actuator elements 112A-112C may elongate/shorten to
control the distance between the lens elements 108 and 110. In addition, since
three piezoelectric actuator elements 112A-112C are used to support the first
lens element 108, it may be tilted with respect to a plane perpendicular to the
optical axis of the projection optical system 106. These distance and tilt
adjustments enable the **correction** of any variations in the projected image
which may be caused by possible deflection of the mask 102, such as any
variations in magnification and any distortions due to the deflection.

Detailed Description Text - DETX (22):
    During this scanning projection operation, if the mask 102 is deflected, the
deflection is detected by the mask-deflection detection system 22 as with the
above-described embodiments, and the magnitude of the deflection is calculated

by the arithmetic operation unit 104. The arithmetic operation unit 104
further uses the calculation results to derive the expected adverse effects of
the deflection of the mask 102 on the projected image, and calculates the
voltage control values indicating the respective voltages to be applied to the
piezoelectric actuator elements 112A-112C in order to **correct** the expected
adverse effects on the projected image. The voltage control values are
supplied to the voltage control unit 118, so that the voltages applied to the
piezoelectric actuator elements 112A-112C in the projection optical system 106
are controlled. In this manner, the lens element control of the projection
optical system 106 is performed such that the relationship between the lens
elements 108 and 110 is adjusted so as to **correct** any adverse effects of the
mask-deflection on the projected image.

Detailed Description Text - DETX (24):
   The mask 172 may be deflected in the Z-direction as indicated by arrows FQ
and FR due to some causes such as the gravity. It may be ideal that the
deflection of the mask 102 is **corrected** with respect to both of the X- and
Y-directions corresponding to arrows FQ and FR. Nevertheless, the light beam
170 has an elongate cross section which produces an elongate light spot on the
mask. 172 which is short in the scanning direction (or the X-direction) and
wide In the lateral direction (or the Y-direction). In view of such particular
shape of the light spot produced by the light beam 170, it is more practical
for the pattern projection purposes that the deflection along the X-direction
as indicated by arrow FQ is **corrected** by focusing and/or levelling operations,
and only the deflection along the Y-direction as indicated by arrow FR is

eliminated.

Detailed Description Text - DETX (25):
    Thus, in this embodiment, a set of piezoelectric actuator elements 174A-174F
are disposed such that the deflection of the mask 172 along the Y-direction as
indicated by arrow. FR may be eliminated thereby, or the positions along a
pair of edges of the mask 172 extending in the moving direction of the light
beam 170. The deflection of the mask 172 is detected and **corrected** in the same
manner as with the second embodiment described above. For example, when the
light beam 170 falls on the mask 170 at the position near two of the
piezoelectric actuator elements, 174C and 174D, the deflection may be **corrected**
by activating them. In this manner, the mask 172 may be caused to produce a
corrective, counteractive deflection as indicated by arrow
FS, which may cancel
out the original deflection as indicated by arrow FR.

Detailed Description Text - DETX (26):
    Various modifications and alterations may be made to the embodiments
described above, and are apparent to those skilled in the art having read the
above disclosure. Such modifications and alterations include the followings.
(1) While the first embodiment utilizes a pneumatic pressure for the purpose of
correcting the deflection of the mask, it is also possible to use a hydraulic
pressure. However, to use a pneumatic pressure is preferable in view of the
handling of a mask and the prevention of leakage of a liquid.
 (2) While each
of the embodiments described above detects the deflection of the mask at a
single point on the mask, they may be modified such that the deflection is
detected at a plurality of points on the mask and an optimal
correction for the

deflection may be calculated by.using an appropriate arithmetic operation such
as averaging and/or least-squares method. In order to detect the deflection at
a plurality of points on the mask, a plurality of mask-deflection detection
systems, each corresponding to that shown above, may be used. Alternatively, a
diffraction grating may be used to produce a plurality of light beams from a
single light beam output from a single light source, which enables
simplification of the arrangement. (3) With each of the second, third and
fourth embodiments described above, a magnitude of the deflection of the mask
may be detected at each of a plurality of points on the mask and a voltage
control value may be derived for each of the piezoelectric actuator elements
individually. This enables an appropriate **correction** of an asymmetric
deflection of a mask. (4) While the embodiments described above use the
piezoelectric actuator elements, any of various other known actuators may be
used for this purpose, including electrostrictive and magnetostrictive actuator
elements. Further, the number of actuators may be varied if desired. (5) The
features of different embodiments may be combined. For example, the technique
for **correcting** the mask-deflection using the projection optical system as used
in the third embodiment may be incorporated in the wafer exposure apparatus
according to the first and second embodiments. (6) With the third embodiment,
two detection fields in which the detection points for detecting the mask
deflection lie may be defined on opposite sides of the illumination field of
the light beam 100 in the scanning direction, so that the magnitude of the
deflection of the mask may be detected within such one of the detection fields
that is temporary in advance of the illumination field moving relative to the

mask in the scanning direction. This enables the real-time
correction of the
projected image of the mask pattern depending on the
magnitude of the
deflection of the mask within the illumination field of the
light beam 100.

Detailed Description Text - DETX (28):
   As described above, according to the embodiments of the
present invention
for achieving the above-mentioned first object, the
deflection of a mask is
detected and either the deflection of the mask is **corrected**
of the projection
image is **corrected** for the deflection of the mask, so that
any lateral
displacements of the features of the pattern and curvature of
the image surface
due to the deflection of the mask by the gravity, as well as
any distortion and
curvature of the image surface due to the thermal expansion
may be reduced and
thus the pattern of a mask may be advantageously performed
and the projected
image of the pattern of the mask shows good accuracy and
stability.

Detailed Description Text - DETX (32):
   The reticle R is supported by and held on a reticle holder
207 at four
points by vacuum suction, for example. The reticle holder
207 is supported by
a reticle stage RST through three extendable/contractible
actuator elements
208. The reticle stage RST is carried on a reticle base 209
and arranged to be
driven by a linear motor (not shown) for continuous linear
movement in the
X-direction as well as to be driven for minute **corrective**
movement in the
X-direction, the Y-direction and the rotational direction.
There are provided
two movable mirrors 211m (only one of them is shown) fixedly
mounted on the top
surface of the reticle holder 207 and corresponding two laser
interferometer

units 211 (again, only one of them is shown) fixedly mounted on certain,
stationary parts of the exposure apparatus outside the reticle holder 207. The
movable mirrors 211m and the laser interferometer units 211 cooperate to
measure the two-dimensional position of the reticle holder 207 (and thus of the
reticle R). A main control system 214 serves to provide general control of the
entire exposure apparatus. A reticle stage drive system 212 serves to control
the operation of the reticle stage RST based on the measurements supplied form
the laser interferometer units 211 and the control information from the main
control system 214. An image formation characteristics control unit 215
serves, under the control of the main control unit 214, to control the
actuation amounts of the three actuator elements 208 so as to provide fine
adjustment of the height (or the position in the Z-direction) and tilt angles
of the reticle R such that certain distortions (including any errors in the
demagnification ratio) may be adjusted within limited adjustment ranges.

Detailed Description Text - DETX (34):
    The projection optical system PL used with this embodiment is provided with
an image formation characteristics **correction** mechanism. This mechanism
comprises a first set of three extendable/contractible actuator elements 217
mounted on a lens barrel 216 of the projection optical system PL, a first
movable lens-frame 218 holding a first lens element 219 and supported by the
lens barrel 216 through the first set of actuator elements 217, a second set of
extendable/contractible actuator elements 218 mounted on the first movable
lens-frame 218, and a second movable lens-frame 221 holding a second lens
element 222 and supported by the first movable lens-frame 218

through the
second set of actuator elements 218. The main control system 214 operates the
image formation characteristics control unit 215 to control the actuation
amounts of the six actuator elements 217 and 220 so as to provide fine
adjustment of the positions and/or tilt angles of the first and second lens
elements 219 and 222 such that certain distortions (including any errors in
demagnification ratio) produced by the projection optical system PL may be
adjusted within limited adjustment ranges.

Detailed Description Text - DETX (44):
    When the above-mentioned data representing the expected lateral
displacements of the projected images on the wafer is supplied to the main
control system 214, it compensates the distortion data stored in the
internal-memory with the supplied data so as to generate updated distortion
data which represents the distortion contributed solely by the projection
optical system PL, and overwrite the internal memory with the updated
distortion data. Further, each time a new reticle for actual exposure process
is placed and held on the reticle stage RST, the surface shape of that reticle
is measured by the surface shape detection system 230, and then the expected
lateral displacements of the projected images which are expected to be produced
by the measured surface shape (i.e., the expected variation in the distortion)
are calculated prior to the exposure process performed using that reticle.
Then, during the scanning projection exposure process, the main control system
214 calculates the expected total distortion by summing the distortion
contributed solely by the projection optical system PL and the expected lateral
displacements of the projected images to be caused by the

surface shape of that
reticle, and controls the actuation amounts of actuator
elements 208, 217 and
220 through the image formation characteristics control unit
215 so as to
cancel out the expected total distortion. These actuation
amounts of the
actuator elements may vary during an exposure operation of
one shot area
depending on the current X-coordinate of the moving reticle.
In this manner,
the distortion contributed solely by the projection optical
system PL may be
evaluated with precision even when the test reticle used has
a poor
surface-flatness. Further, any variation in the distortion
which may be caused
by the surface shape of a reticle used for the exposure
process can be
corrected during the exposure process, so that the resultant
projected image of
the pattern transferred onto each shot area on a wafer can be
free from any
distortion. Accordingly, when overlay exposures are made,
the overlay errors
may be minimized.

Detailed Description Text - DETX (45):
    Alternatively, in a case where the projection optical
system PL used has
been highly **corrected** for and thus free from any distortion,
the image
formation characteristics of the projection optical system PL
may be controlled
such that only the expected lateral displacements of the
projected images to be
caused by the surface shape of the reticle R may be
eliminated. In this
manner, any distortion of the transferred pattern may be
minimized even when
the pattern-bearing surface of the reticle R has a poor
surface-flatness.

Detailed Description Text - DETX (47):
    FIG. 12 shows a schematic representation of the reticle R,
the projection

optical system PL and the wafer W as viewed in the scanning direction (or the
X-direction) in the projection exposure apparatus of FIG. 10. As shown in FIG.
12, the reticle R held on the reticle holder 207 has a pattern-bearing surface
240 on which a pattern 242 (such as a distortion evaluation pattern) formed
thereon, and the image of the pattern 242 is projected through the projection
optical system PL onto the wafer W. Assuming that the projection optical system
PL is free from any distortion, the image of the pattern 242 should be
projected onto the wafer W at the desired position (or designed position). In
such a case, the contact surfaces of the reticle holder 207 in contact with the
reticle R lie in a plane perpendicular to the optical axis AX of the projection
optical system PL, and will not suffer from any **deformation,**
and the
pattern-bearing surface of the reticle R is maintained to be completely flat.

Detailed Description Text - DETX (63):
    In the above description, 1) the deflection of the reticle R by the gravity,
2) the irregularity in the pattern-bearing surface of the reticle R, and 3) the
irregularities in the contact surface of the reticle holder 207 in contact with
the pattern-bearing surface of the reticle R are described together with the
resultant **deformation** of the pattern-bearing surface of the reticle R and
lateral displacements of the features of the pattern on the pattern-bearing
surface. In some cases, one of these three major factors in distortion may
have much greater contribution than the other two. In other cases, two may
have greater contributions than the third. In further cases, each of the three
may have relatively small contributions but their contributions are cumulative
so that the resultant lateral displacements of the features

of the pattern is
relatively great. Under the circumstances, it is possibly desirable to select
one or two may be selected among the three factors and be taken into
consideration for making adjustment to the projection optical system PL for
correction of the distortion which could otherwise occur.

Detailed Description Text - DETX (69):
    In FIGS. 13 to 15, one-dimensional lateral displacement of the feature of
the pattern on the pattern-bearing surface of the reticle R is shown. However,
in this embodiment, the reticle R is held on the reticle holder 207 at four
points by vacuum suction. Thus, the deflection of the reticle R by the gravity
will actually cause the pattern-bearing surface to deform into a nearly
spherical surface shape, so that the feature of the pattern on the
pattern-bearing surface produces a two-dimensional lateral displacement in the
X- and Y-directions. Therefore, in order to derive the lateral displacements
of the projected images due to the **deformation** of the pattern-bearing surface
of the reticle R more accurately, it is desirable that two-dimensional lateral
displacements of the features of the pattern on the pattern-bearing surface are
derived from the surface-shape of the pattern-bearing surface and the values of
the distortion may be adjusted with respect to both the X- and Y-directions.

Detailed Description Text - DETX (78):
    In a projection exposure method according to the present invention for
achieving the above-mentioned second object, the surface shape of the
pattern-bearing surface of a mask is measured and stored, and then the expected
lateral displacements of the features of the projected pattern image which are

expected to be produced by the surface shape are calculated. Then, the
measurements of the distortion of the projection optical system are adjusted
with the expected lateral displacements so as to derive with precision the
distortion to be produced solely by the projection optical system. In the
actual exposure process, an exposure is made while the positions of the
features of the projected pattern image are partially **corrected** such that the
distortion may be **corrected**. By virtue of this, the distortion of the
projected image of the pattern may be **corrected** with great accuracy. As the
result, excellent image formation characteristics may be advantageously enjoyed
even if the mask has a poor flatness.

Detailed Description Text - DETX (79):
    In another projection exposure method according to the present invention for
achieving the above-mentioned second object, any irregularities in the contact
surface of a mask and/or in the contact surface of a support member for
supporting the mask are measured and stored, and then the expected surface
shape of a pattern-bearing surface of the mask which is expected to occur when
the mask is secured onto the support member by vacuum suction is derived from
the measured irregularities. Then, the expected lateral displacements of the
features of the projected pattern image which are expected to be produced by
the surface shape are calculated, and the measurements of the distortion of. the
projection optical system are adjusted with the expected lateral displacements.
Then, an exposure is made while the positions of the features of the projected
pattern image are partially **corrected** such that the distortion may be
corrected. By virtue of this, the distortion of the projected pattern image

may be **corrected** with great accuracy. As the result, excellent image formation
characteristics may be advantageously enjoyed even if the mask has a poor
flatness.

Detailed Description Text - DETX (84):
   The reticle R is supported by and held on a reticle holder 307 at four
points by vacuum suction, for example. The reticle holder 307 has a pair of
parallel ribs 308A and 308B attached on the bottom surface thereof providing
the reticle holder 307 with a sufficient rigidity for high speed movement. The
ribs 308A and 308B are fixedly mounted on a reticle stage RST. The reticle
stage RST is carried on a reticle base 309 and arranged to be driven by a
linear motor (not shown) for continuous linear movement in the X-direction as
well as to be driven for minute **corrective** movement in the X-direction, the
Y-direction and the rotational direction. There are provided two movable
mirrors 311m (only one of them is shown) fixedly mounted on the top surface of
the reticle holder 307 and corresponding two laser interferometer units 311
(again, only one of them is shown) fixedly mounted on certain, stationary parts
of the exposure apparatus outside the reticle holder 307. The movable mirrors
211m and the laser interferometer units 311 cooperate to measure the
two-dimensional position of the reticle holder 307 (and thus of the reticle R).
A main control system 314 serves to provide general control of the entire
exposure apparatus. A reticle stage drive system 312 serves to control the
operation of the reticle stage RST based on the measurements supplied form the
laser interferometer units 311 and the control information from the main
control system 314.

Detailed Description Text - DETX (90):
    The projection optical system PL used with this embodiment is provided with
an image formation characteristics **correction** mechanism.
This mechanism
comprises a set of three extendable/contractible actuator elements 319 mounted
on a lens barrel 318 of the projection optical system PL and a movable
lens-frame 320 holding a lens element 321 and supported by the lens barrel 318
through the set of actuator elements 319. The main control system 314 operates
an image formation characteristics control unit 315 to control the actuation
amounts of the three actuator elements 319 so as to provide fine adjustment of
the position and/or tilt angles of the lens element 321 such that certain
distortions (including any errors in demagnification ratio) produced by the
projection optical system PL may be adjusted within limited adjustment ranges.
While the above arrangement drives only a single lens element, it may be
preferable to modify it such that two or more lens elements of the projection
optical system PL can be driven in a similar manner so as to enable adjustment
or **correction** for further image formation characteristics (such as, curvature
of field, comma, etc.)

Detailed Description Text - DETX (91):
    It is known that the. image formation characteristics of a projection
optical system PL (such as, the distortion, the position of the image plane,
and others) generally vary with time in a relatively long, continuous operation
of the projection exposure apparatus due to the variation in the atmospheric
pressure, the variation in the ambient temperature, the heat energy buildup in
the projection optical system PL received from the exposure light beam, and

other factors. In order to prevent any adverse effects of
such variation of
the image formation characteristics, adjustment of the image
formation
characteristics of the projection optical system PL is
performed. For the
adjustment, there are provided an atmospheric pressure sensor
(not shown) for
continuously sensing the atmospheric pressure and a light
intensity sensor (not
shown) for continuously sensing the light intensity of a
partial light beam
extracted from the illumination light beam IL. These sensors
continuously
provide detection signals, which are supplied to the main
control system 314.
The main control system 314 uses the detection signals to
drive expected
variations in the image formation characteristics, and
operates the image
formation characteristics control unit 315 and/or a drive
mechanism for driving
the material support 323 in the Z-direction (or the defocus
distance **correcting**
mechanism) so as to adjust the image formation
characteristics of the
projection optical system PL such that the expected
variations in the image
formation characteristics may be cancelled out. In this
embodiment, the image
formation characteristics control unit 315 and the material
support 323 are
also used to **correct** the image formation characteristics for
the errors due to
the **deformation** of the reticle R.

Detailed Description Text - DETX (92):
    A reference mark plate 322, which is made from a glass
plate having its top
surface coated with an opaque film **layer,** is mounted on the
material support
323 at a position adjacent to the wafer W placed on the
material support 323.
The top surface of the reference mark plate 322 is nominally
level with the
surface of the wafer W and has slits 322x and 322y extending
in the Y-direction

and the X-direction, respectively, formed in the opaque film
layer and allowing
light rays to pass therethrough. The slits 322x and 322y are
used for
measuring the image formation characteristics including the
distortion and the
position of the image plane.

Detailed Description Text - DETX (96):
   Next, we will describe a mechanism for measuring the
deformation of the
reticle R. In the projection exposure apparatus of FIG. 18,
the reticle holder
307 has a pair of reinforcement ribs 308A and 308B for
enhancing the rigidity
of the reticle holder 307 while the projection optical system
PL is provided at
its upper end with the drive mechanism for a lens element, so
that the space
between the bottom surface of the reticle base 309 (or of the
reticle stage
RST) and the upper end of the projection optical system PL is
very tight. In
view of this, in this embodiment, surface shape detection
system 330 for
detecting the surface shape of the pattern-bearing surface of
the reticle R
(such as, any irregularities in and tilt of the
pattern-bearing surface) is
disposed below the reticle stage RST and at a position off
the above-mentioned
space between the bottom surface of the reticle stage RST and
the upper end of
the projection optical system PL toward the scanning
direction.

Detailed Description Text - DETX (97):
   In the projection exposure apparatus of this embodiment,
each time a new
reticle is loaded and held onto the reticle holder 307, the
pattern-bearing
surface of the reticle is measured and stored. Accordingly,
it is unnecessary
to measure the surface shape of the pattern-bearing surface
of the reticle
during the scanning projection exposure process as performed

using the
illumination light beam IL for exposure. Rather, during the
scanning
projection exposure process, the stored data representing the
surface shape of
the pattern-bearing surface in relation with the associated
X-coordinates of   .
the reticle stage RST, is read out and used to **correct** any
variation in the
image formation characteristics. Because the surface shape
of the reticle R
may be measured an appropriate position away from the optical
axis AX of the
projection optical system PL, the surface shape detection
system 330 need not
be disposed in the above-mentioned tight space between the
bottom surface of
the reticle stage RST and the upper end of the projection
optical system PL.

Detailed Description Text - DETX (106):
    In FIG. 22, the reference member 310 has been moved in the
+X-direction
relative to the projection optical system PL, and the three
detection light
beams DLA, DLB and DLC are projected from the light sources
331A 331B and 331C,
respectively, of the surface shape detection system 330 of
FIG. 19 onto the
reference surface (bottom surface) of the reference member
310 at the three
measuring points 341A, 341B and 341C, respectively, which
measuring points lie
on a center line of the reference surface extending in the
Y-direction at the
center with respect to the X-direction. In this manner, the
arithmetic
operation unit 313 of FIG. 18 detects the positions in the
Z-direction of the
reference surface at the measuring points 341A, 341B and
341C, designated by
ZA.sub.0, ZB.sub.0 and ZC.sub.0. The, as shown in FIG. 23, a
part of the
pattern-bearing-surface of the reticle R for the actual
exposure process is
moved into a position within the detection area of the
surface shape detection

system 330, and the position of that portion of the
pattern-bearing surface is
measured. An example is described here, assuming that when
the measurement of
the position of the pattern-bearing surface of the reticle R
is performed, the
pattern-bearing surface shows a **deformation** which is uniform
in the scanning
direction and the reticle R is located at a starting position
for the scanning
projection exposure to the first of the shot areas defined on
a wafer.

Detailed Description Text - DETX (109):
   FIG. 21 is a schematic side elevation of the reticle R on
the reticle holder
307, the projection optical system PL and the wafer W, as
viewed in the
+X-direction (or the scanning direction), illustrating an
exemplified, possible
deformation of the pattern-bearing surface of the reticle R.
The reticle R
indicated by the solid lines is completely flat with its
pattern-bearing
surface 340 coincident with the reference surface of the
reference member (not
shown), and the surface of the wafer W is coincident with the
image plane of
the pattern-bearing surface 340 defined by the projection
optical system PL.
The reticle R indicated by the imaginary lines is deformed by
the gravity with
its pattern-bearing surface 340A deflected thereby. The
magnitudes of the
deflection of the pattern-bearing surface 340A from the
reference surface at
the measuring points are represented by the data representing
the positions in
the Z-direction, .DELTA.ZA(x.sub.1), .DELTA.ZB(x.sub.1) and
.DELTA.ZC(x.sub.1).
The main control system 314 calculates the expected
displacements of the image
surface 342A defined by the projection optical system PL
which are expected to
occur due to the deflection of the pattern-bearing surface
340A, from the
demagnification ratio .beta. of the projection optical

system PL and the data
representing the positions in the Z-direction. From the
result of the
calculation, the field curvature of the image surface 342A
and the variation
.DELTA.Z in the average focus position of the image surface
342A are derived.
Then, the main control system 314 operates the image
formation characteristics
control unit 315 of FIG. 18 to **correct** the projection optical
system PL for the
field curvature, by controlling the actuation amounts of the
actuator elements
319. This **correction** may cause an associated variation in
the average focus
position. Thus, the main control system calculates the
resultant variation
.DELTA.Z' in the average focus position, and vary the desired
value of the
focus position of the surface of the wafer W (which is
supplied to the wafer
stage control system 326) by -.DELTA.Z'. In this manner,
corrections are made
for the field curvature and the defocus both produced by the
deflection of the
pattern-bearing surface of the reticle R, so that the surface
of the wafer W
may be brought into a position at which it will be coincident
with the actual
image surface of the patten-bearing surface of the reticle R
with precision.

Detailed Description Text - DETX (110):
    If it is expected that the **deformation** of the
pattern-bearing surface of the
reticle R would also affect the distortion produced by the
projection optical
system PL, the image formation characteristics control unit
315 is operated to
make **correction** for the distortion as well. If the magnitude
of the
deformation of the pattern-bearing surface of the reticle R
considerably varies
depending on the position in the scanning direction, it is
preferable to
measure the positions in the Z-direction ZA(x.sub.i),

ZB(x.sub.i) and
ZC(x.sub.i) at the three measuring points on the
pattern-bearing surface of the
reticle R through the surface shape detection system 330 and
derive the
corresponding differentials from the reference surface, each
time the
X-coordinate of the reticle stage RST has increased by a
predetermined distance
to be X.sub.i (i=2, 3, . . .) Then, the average surface of
the
pattern-bearing surface may be determined and the image plane
of the average
surface be used as the desired image plane with which the
surface of the wafer
W should be coincident, or alternatively, the adjustment for
the field
curvature as adjusted by the image formation characteristics
control unit 315
and the adjustment for the desired value of the focus
position as adjusted by
the material support 323 may vary depending on the
X-coordinate of the reticle
stage RST.

Detailed Description Text - DETX (113):
    Referring next to the flow chart of FIG. 24, we will
describe an exemplified
sequence of operations performed with the projection exposure
apparatus of this
embodiment for measuring the **deformation** of the
pattern-bearing surface of a
reticle and making an exposure while **correcting** the image
formation
characteristics. To begin with, at step 400 in FIG. 24, a
human operator
determines whether the calibration of the image formation
characteristics of
the projection optical system PL, or so-called lens
calibration, is to be
performed. The lens calibration is performed if desired in
view of the
stability of the image formation characteristics of the
projection optical
system PL. If the lens calibration is to be performed, the
process proceeds to
step 401, where the image formation characteristics (relating

to the distortion
and the image plane) are measured using the evaluation marks
of the reference
member 310 under the control of the main control system 314
in the manner as
described above with reference to FIG. 20. Then, the process
proceeds to step
402, where the main control system 314 **corrects** the image
formation
characteristics such that the characteristics may be optimal
with respect to
the reference surface of the reference member 310.

Detailed Description Text - DETX (116):
    Then, the process proceeds to step 406, where the main
control system 314
calculates the expected variation in the image formation
characteristics which
is expected to occur due to the **deformation** of the
pattern-bearing surface of
the reticle R as measured in comparison with the reference
surface in the
manner as described above with reference to FIG. 21 and also
calculates the
correction values necessary to **correct for the deformation** of
the reticle R.
Since a slit-shaped exposure field is used in the scanning
projection exposure,
a finer **correction** can be made by varying the **correction**
values depending on
the position In the scanning direction (or the X-coordinate)
of the reticle
stage RST. For example, if the reticle R suffers from some
torsional
deformation, the tilt angle of the wafer W may be varied
depending on the
torsional angle of the reticle R. That is, it is preferable
to vary the
correction values depending on the X-coordinate of the
reticle stage RST. Note
that the X-coordinate of the reticle stage RST used here is
derived taking into
consideration the differential between the measuring position
(or the position
in the X-direction of the measuring points of the surface
shape detection

system 330) and the exposure position (or the position in the
X-direction of
the optical axis AX of the projection optical system PL).

Detailed Description Text - DETX (117):
   Then, the process proceeds to step 407, where the exposure
process for
printing a circuit pattern of a semiconductor chip is
commenced. For example,
the wafers in a lot are sequentially loaded onto the material
support 323 and
the scanning projection exposure is performed to each of the
shot areas defined
on every wafer. Just before the commencement of the exposure
process, the main
control system 314 derive the total **correction** values by
summing 1) the
correction values derived at step 406 and 2) additional
correction values for
canceling out the expected variation in the image formation
characteristics
which is expected to occur due to variation in the
atmospheric pressure and
absorption of some of the illumination light energy by the
projection optical
system PL. Then, based on the total **correction** values, the
main control system
314 drive the image formation characteristics unit 315 and
the material support   ·
323 to **correct** the image formation characteristics depending
on the
X-coordinates of the reticle stage RST during the scanning
projection exposure
to a particular shot area.

Detailed Description Text - DETX (119):
   As apparent from the above, in this embodiment, the
surface shape of the
pattern-bearing surface of the reticle R is measured by the
surface shape
detection system 330 using the reference surface of the
reference member 310 as
the reference for the measurement, and the measurement result
is used to
correct the image formation characteristics of the exposure

apparatus.
Therefore, even when the measurements produced by the surface shape detection
system 330 suffer fluctuations with time, the surface shape of the
pattern-bearing surface can be measured with precision, with the result that
the exposure process may be performed with the image formation characteristics
maintained at a desired condition with precision.

Detailed Description Text - DETX (120):
    If a reticle which has been used once or more is to be again used, and the
data representing the measured surface shape of that reticle is maintained, as
well as the required precision of the exposure process Is not severe, then the
measurement of the surface shape of the reticle at step 405 may be bypassed to
improve the throughput of the exposure process. Nevertheless, it is generally
preferable not bypass the step 405 because even when the same reticle is to be
used again, the position of that reticle on the reticle holder 307 may be
possibly displaced from the position it occupied when previously used, because
there may be a possible error in the positioning operation of the reticle
loader and/or a possible foreign particle between the reticle and the reticle
holder 307. Further, it is preferable to alert a human operator and stop the
exposure process when a great residual error is expected even after the
correction of the image formation characteristics or the
correction values are
insufficient, which may occur due to the presence of foreign particles or a
great error in size or shape of the reticle.

Detailed Description Text - DETX (121):
    In this embodiment, the surface shape of the reticle R is measured only once
after the placement onto the reticle holder 307. This is

based on the
assumption that the reticle R would suffer no variation in
its surface shape
once it is placed onto the reticle holder 307. However, if
the reticle R is
expected to suffer some variation in its surface shape with
time and/or absorb
some of the illumination light energy to thermally expand so
that remeasurement
would be necessitated, it is preferable to direct the process
again to step 404
and/or step 405 to perform again measurement of the surface
shape. In
addition, while in the above description only the variation
in the shape of the
reticle R is considered, the orientation of the reticle R may
also suffer
variation since the orientation of the reticle stage RST may
possibly vary
depending on the position of the reticle stage RST. This is
a problem relating
not to individual reticles but to the projection exposure
apparatus itself.
Thus, in order to solve this, variations in the orientations
of reticles are
measured for the exposure apparatus in advance, and the
correction values for
the variations are added to the **correction** values for the
surface shape of the
reticle by incorporating them into the **correction** values of
the image formation
characteristics corresponding to the coordinates of the
reticle stage.
Further, if the orientation of the reticle stage RST may
suffer variation
depending on the velocity and/or acceleration of the reticle
stage RST when
moved for scanning, it is preferable to make a **correction** for
such variation in
the same manner as above.

Detailed Description Text - DETX (123):
   Further, while in this embodiment the image formation
characteristics is
corrected by means of the drive of the lens element in the
projection optical
system PL and the attitude control of the material support

323 on the wafer
stage WST, the image formation characteristics may be
alternatively performed
in other way. For example, the reticle stage RST may be
provided with an
attitude control mechanism, and the attitude control of the
reticle may be
performed by feedback control using the attitude control
mechanism and the
surface shape detection system 330 for providing feedback of
the position of
the pattern-bearing surface of the reticle. In such a case,
It is preferable
that the measuring points defined by the surface shape
detection system 330
comprise three or more points which do not lie in a line, in
order to enable
determination of a plane.

Detailed Description Text - DETX (125):
    In a scanning projection exposure method according to the
present invention
for achieving the above-mentioned third object, the surface
shape of the
pattern-bearing surface of a mask is measured prior to making
a scanning
projection exposure, and the image formation characteristics
are **corrected**
based on the measurement result during the scanning
projection exposure, so
that the sensor for measuring the surface shape of the
pattern-bearing surface
of the mask may be advantageously disposed with ease even
when there is little
space between the projection optical system and a mask stage
since it may be
disposed at a position away from the projection optical
system to the scanning
direction. As the result, by measuring the **deformation** of
the mask, the
expected variation in the image formation characteristics
which is expected to
be produced by the **deformation** may be derived and an
appropriate **correction** may
be made.

Detailed Description Text - DETX (127):
   With a scanning projection exposure apparatus according to
the present
invention for achieving the above-mentioned third object, the
scanning
projection exposure methods described above for the third
object may be
conveniently performed. In the case where a reference
surface is formed on a
mask stage for moving the mask such that the reference
surface may be
substantially level with the pattern-bearing surface of the
mask, and a
calibration of the shape measurement system is performed
using the reference
surface, it is sufficient for the shape measurement system to
have such
stability that the measurements it provides are stable only
for a very short
time from when the reference surface has been measured to
when the surface of
the mask has been measured. Thus, even if the measurements
produced from the
shape measurement system tend to suffer fluctuations within a
relatively short
time (i.e., the shape measurement system has a poor
stability), the surface
shape of the mask may be measured with precision so as to
make an appropriate
correction for the variation. By virtue of this, the shape
measurement system
may have a relatively simple arrangement.

Detailed Description Text - DETX (133):
   The uppermost of the lens elements of the projection
optical system PL is a
correction lens element 515 having a flat upper surface and a
cylindrical
concave lower surface as shown in cross-section in FIG. 25,
which cross-section
is perpendicular to the longitudinal axis (extending
perpendicular to the
drawing sheet surface of FIG. 25) of the reticle holder 513.
Accordingly, the ·
sectional side view of the **correction** lens element 515 along
the longitudinal
axis of the reticle holder 513 would show a shape of a

rectangle (or straight
band). The shape of the **correction** lens element 515 is so designed as to
correct the errors in image formation characteristics due to the deflection of
the reticle R, so that the image of the pattern projected on the wafer W may be
corrected by the correction lens element 515 with precision.

Detailed Description Text - DETX (138):
    The projection exposure apparatus 500' has a unique feature that it has a
projection optical system PL comprising combined **correction** lens elements 521
and 525 having no rotational symmetry about the common optical axis and
associated with respective manipulation mechanisms 523 and 527. The **correction**
lens elements 521 and 525 are independently rotatable about the common optical
axis by means of the associated manipulation mechanisms 523 and 527,
respectively. In the adjustment process, the manipulation mechanisms 523 and
527 may be operated to rotate the non-rotationally-symmetric, **correction** lens
elements 521 and 525 about the common optical axis, so as to adjust the
rotational positions of the lens elements 521 and 525. An example of each
manipulation mechanism 523, 527 may comprise a rotary member having a plurality
of holes extending in the direction of the optical axis and capable of
insertion therein with an adjustment bar. When a human operator rotates the
adjustment bars of the manipulation mechanisms 523 and 527 about the common
optical axis so as to change the relative, optical positions of the **correction**
lens elements 521 and 525, the resultant vector may be directed to any desired
direction.

Detailed Description Text - DETX (140):

This exemplified adjustment process includes the determination of a reticle
size (step 541), the determination of the shape and positions of the support
portions of the reticle R (step 562), the calculation of the expected
deflection of the reticle R (step 566) and the calculation of the expected
errors produced by the expected deflection (step 564), which corresponds to the
steps 561, 562, 563 and 564, respectively, shown in the design process of FIG.
26. However, the expected errors thus calculated are taken into consideration
in the adjustment process for the projection lens as fixed offsets. In other
words, the design of the projection lens itself is so conducted as to minimize
the lens aberrations, while the desired values for adjustment process are set
such that they may cancel out the expected errors to be produced by the
deflection of the reticle used. The adjustment may be performed by rotating
non-rotational-symmetric, **correction** lens elements as described with reference
to FIG. 27, or alternatively by increasing the distance between the lens
elements by a fixed offset from the design value.

Detailed Description Text - DETX (142):
    In this exemplified adjustment process, the projection lens undergoes the
adjustment using design values only in the fabrication process of the
projection lens (step 571). Thereafter, the error components due to the
deflection of the reticle are determined by, for example, making a projection
exposure (step 572), and the error components are fedback to the desired values
which the aberrations are to be caused to approach. The errors components due
to the **deformation** of the reticle may be separated from the remaining
components by, for example, acquiring the data representing the wavefront of

the projection lens with no reticle used, so as to determine the aberrations of
the projection lens itself, and then measuring the errors in the projected
pattern image which are produced when an characteristics evaluation reticle is
used, through a coordinate measurement device or the like. For evaluation of
the projected image of the reticle pattern, the errors contributed by the
projection optical system as well as the errors contributed by the original
shape of the reticle are all removed so as to derive only the error components
due to the deflection of the reticle. Then, adjustment is performed with
respect to those components to cancel out them, such that the resultant errors
are reduced zeros. This is advantageous because if adjustment were performed
using only the result of the actual printing process in the normal fabrication
of products, errors may be increased due to the difference in the deflection
between the test reticle used for the adjustment process and the reticle used
for actual printing process in the fabrication of products. After the
adjustment of the projection lens (step 574), an exposure is made again (step
542). Thereafter, if the errors are smaller than the corresponding acceptable
upper limits (YES at step 574), then the entire adjustment process is
completed.

Detailed Description Text - DETX (144):
   Alternatively, in the case where the design of the projection lens is not
modified, the **correction** values for the errors may be provided as the desired
values for the adjustment, so that an exposure of a device pattern may be
performed with great accuracy as well.

Claims Text - CLTX (1):

1. A projection exposure method for exposing a substrate
through a
projection optical system with a pattern formed on a mask,
the mask being
supported by a predetermined support member, comprising: a
first step of
calculating an amount of lateral variation of a pattern image
in a direction
perpendicular to an optical axis of the projection optical
system, the
variation being caused by error factors including
irregularities in a contact
surface of the mask in contact with the support member and/or
irregularities in
a contact surface of the support member in contact with the
mask; a second
step of determining a distortion produced solely by the
projection optical
system; a third step of obtaining a total expected
distortion that corresponds
to a summation of the distortion produced solely by the
projection optical
system and the calculated variation of the positions at which
the image of the
pattern of the mask is formed; and a fourth step of exposing
the substrate
while partially **correcting** the position at which the image of
the pattern of
the mask is formed through the projection optical system
based on the total
expected distortion.

Claims Text - CLTX (2):
    2. A projection exposure method for exposing a substrate
through a
projection optical system with a pattern formed on a
pattern-bearing surface of
a mask, comprising: a first step of calculating an amount of
lateral variation
of a pattern image, the variation being caused by
irregularities in the
pattern-bearing surface of the mask; a second step of
determining a distortion
produced solely by the projection optical system; a third
step of obtaining a
total expected distortion by a summation of the distortion
produced by the

projection optical system and the calculated variation of the
pattern image;
and a fourth step of **correcting** the total expected
distortion.

Claims Text - CLTX (4):
    4. A projection exposure method according to claim 2,
wherein the first
step comprises: calculating an amount of lateral variation of
the pattern
image, caused by a thermal **deformation** of the mask.

Claims Text - CLTX (12):
    12. A projection exposure method according to claim 2,
wherein the fourth
step comprises the step of scanning exposing the substrate
with the pattern
formed on the mask by moving the mask and the substrate in
synchronization with
teach other while partially **correcting** the position at which
the image of the
pattern of the mask is formed through the projection optical
system, based on
the total expected distortion.

Claims Text - CLTX (14): ·
    14. A projection exposure method for exposing a substrate
through a
projection optical system with a pattern image formed on a
pattern-bearing
surface of a mask, comprising: a first step of determining a
distortion
produced solely by the projection optical system; a second
step of obtaining a
total expected distortion by a summation of the distortion
produced solely by ‥
the projection optical system and an amount of lateral
variation of the pattern
image, caused by a self-weight of the mask; and a third step
of exposing the
substrate with the pattern image while partially **correcting**
the position at
which the pattern image of the mask is formed through the
projection optical
system based on the total expected distortion.

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